



Ionospheric Mappers

*We shall not cease from exploration,
and the end of all our exploring
will be to arrive where we started
and know the place for the first time.*

T.S. Eliot



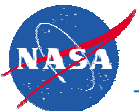
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IM Study Chronology

Date	Event	Concept
1/12/00	Initial Thoughts Of R. Pfaff	16 Satellites, 4 Launches
1/12/00 to 3/15/00	Engineering Team Studies	Instruments, Spacecraft, Orbits
3/16/00	IM Mission Definition Team Meeting	Instruments, Spacecraft, Orbits
3/31/00 to 4/2/00	IMDC Pre-Work	8 Satellites, 2 Launches
4/3/00	Strawman Payload From R. Pfaff	5 Instrument Packages
4/3/00 to 4/7/00	IMDC Study	8 Satellites, 1 Launch, FOO
4/10/00 to 5/5/00	Mission Costing (Full Scope)	8 Satellites, 2 Launches
	Mission Costing (Reduced Scope)	4 Satellites, 1 Launch
5/31/00	Program Operating Plan Submittal	4 Satellites, 1 Launch*

** Exceeded NASA/HQ cost target and cost-capped funding profile allocation*



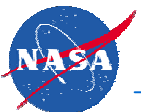
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IM Concept Evolution

The Ionospheric Mappers mission was initially envisioned as a constellation of well-instrumented, small spacecraft in polar and low inclination orbits. The GSFC engineering team worked closely with the science team leader to develop a concept that could be further refined during the scheduled IMDC study. From the outset, the engineering team expressed concern that the number of instruments, spacecraft, launches, and desired orbit locations would most likely present a cost challenge of considerable proportions. To circumvent this issue, it was decided to proceed with a *building block concept of identical elements* that could meet science requirements and could be replicated as many times as the budget allocation allowed.

The charts that follow describe a space and ground system concept that accommodates the suite of instruments identified by the science team and attempts to maximize packaging of elements for the polar launch. Low inclination elements were treated as payloads of opportunity, and hence no specific orbit analysis or launch vehicle accommodation is shown.



IM Mission Profile



Description: A small constellation of satellites that provides global coverage and characterization of the ionosphere at all latitudes and local times

Instruments: Five in-situ instrument packages per polar orbiting spacecraft for combined particles, fields, and gas properties measurements as well as a GPS tomography instrument and an ionospheric sounder; no particles package required for low inclination spacecraft

Spacecraft: Eight identical, three-axis stabilized spacecraft containing a propulsion system for orbit maneuvers, station-keeping, and disposal with six spacecraft each in a different polar orbit plane 30° apart, and two spacecraft at low inclination in the same orbit plane 180° apart

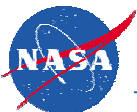
Launch Date: April, 2009

Mission Life: 2 years with an optional 3-year extension of mission operations as resources permit

Orbits: 450 km circular orbit planes at 87° inclination along with one low inclination (15° to 45°) orbit plane

Space Access: One launch on a Medium Class ELV from WTR for high-inclination elements and flights of opportunity from ETR for low-inclination elements

Key Technologies: Smaller instruments or instrument packages and enhancing technologies at the subsystem or component level

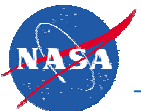




IM Mission Time Line

The following *serial* time spans are assumed for mission planning with July 1, 2000 as the initial reference date:

- 3 years for mission unique technology development
- 2 years for studies, project formulation, and mission definitization
- 4 years from approval to launch readiness
- April 2009 launch
- 2 years for baseline mission operations
- 3 year mission extension (option for evaluation)



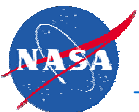


IM Mission Objectives

The IM mission employs a constellation of small, well-instrumented satellites distributed in latitude and local time around the Earth to gain knowledge of how the ionosphere behaves as a system.

Specific mission objectives are as follows:

- Global characterization and understanding of the Earth's ionosphere / upper atmosphere (100 to 1000 km) and its connection to the Sun, solar wind, and magnetosphere
- Major improvements of ionosphere and thermosphere specification models
- Improvement of forecast and nowcast accuracy
- Establishment of a quantitative baseline for Sun-climate studies



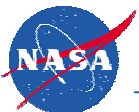


IM Instrument Complement

The baseline IM instrument complement has been grouped into five distinct measurement packages* listed below:

- (1) Combined Particles Instrument (includes high energy electron sensor, high energy ion sensor, low energy electron sensor, and an electronics box)
- (2) Combined Fields Instrument (includes Langmuir probe, 2 m boom and magnetometer, E-field booms and spheres, and an electronics box)
- (3) Combined Gas Properties Instrument (includes ion velocity meter sensor, neutral wind sensor, ion/neutral mass spectrometer sensor, and an electronics box)
- (4) GPS Tomography Instrument (includes dishes, a patch antenna, and an electronics box)
- (5) Ionospheric Sounder

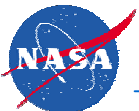
*Instrument system parameters, shown in the table that follows, are based on heritage from DE and MMS/GEC studies.



IM Instrument Parameters



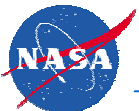
TYPE/CLASSIFICATION	NOTES	SIZE	MASS	POWER	DATA RATE
		LxWxH or DxH (cm)	(kg)	Peak/Survey/Low (W)	Peak/Low (kbps)
Combined Particles Instrument	Polar Orbit Only				
High Energy Electron Sensor		18x18x3.8	6		
High Energy Ion Sensor		13x13x20	6		
Low Energy Electron Sensor		18x18	2		
Electronics Box		25x25x20	10	15/10/4	270/30
SubTotal			24	15/10/4	270/30
Combined Fields Instrument	Polar & Low Inclination				
Langmuir Probe and Boom		0.5x100	1		
Magnetometer on 2 m Boom		12x7x9	2		
E-Field Booms and Spheres		33x18x89	21		
Electronics Box		25x25x20	8	18/12/5	500/20
SubTotal			32	18/12/5	500/20
Combined Gas Properties Instrument	Polar & Low Inclination				
Ion Velocity Meter Sensor		10x20x20	2		
Neutral Wind Sensor		15x20	2		
Ion/Neutral Mass Spectrometer Sensor		20x15x40	6		
Electronics Box		25x25x20	8	22/14/5	30/10
SubTotal			18	22/14/5	30/10
GPS Tomography Instrument	Polar & Low Inclination				
Dishes		18x10			
Patch Antenna		4x4x1			
Electronics Box		10x15x15		11/7/4	4.0/4.0
SubTotal			5	11/7/4	4.0/4.0
Ionospheric Sounder	Polar & Low Inclination	25x25x20		14/7/2	40/4
SubTotal			8	14/7/2	40/4
Total			87	80/50/20	844/68
Summary					
Polar Orbiting Spacecraft	All instruments		87	80/50/20	844/68
Low Inclination Spacecraft	No particle instruments		63	65/40/16	574/38





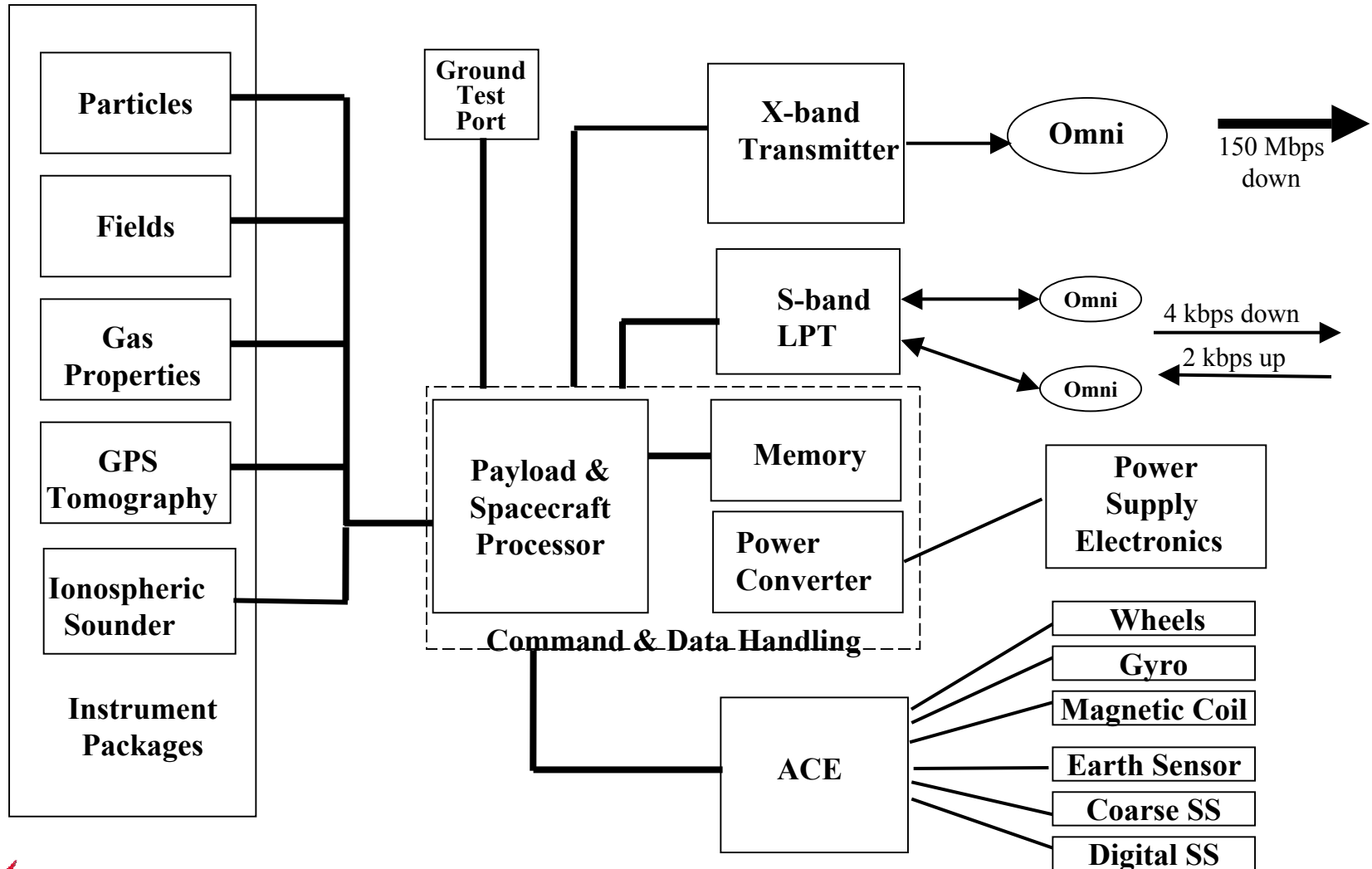
IM System Synopsis

- Mission objectives require the deployment of multiple satellites into different orbit planes while minimizing launch costs and spacecraft propulsion.
- Space and ground systems must support continuous operation of the scientific instruments for a period of at least two years.
- Although a single-string spacecraft design approach was adopted to minimize mass to orbit, some redundancy is inherently achieved by employing a constellation of identical satellites.
- Two geographically separate ground stations (Alaska, S.Florida) are required to ensure communications (uplink and downlink) with IM high and low inclination satellite elements.
- Innovative approaches to the design, fabrication, assembly, integration, and testing of multiple spacecraft and instrument packages are needed to make the most efficient use of available resources.





IM System Block Diagram





IM Mass Summary

Element			Polar Mass	Low Inc Mass
			(kg)	(kg)
Instrument Packages			87	63
Spacecraft Bus			256	256
	Mechanical	107		
	Power	48		
	Thermal	32		
	Attitude Control	21		
	Propulsion	15		
	C&DH	11		
	Communications	10		
	Harness	12		
Dry Mass			343	319
Propellant			79	
Mass Per Satellite			422	
Total Mass For 6 Satellites			2532	
Transition Adapter			80	
Total Mass To Orbit			2612	
Delta II 7920-10 Lift Capability To 450 km			3450	
Launch Mass Margin			32.0%	

Values are best estimates and do not include contingency.

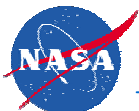




IM Power Summary

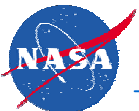
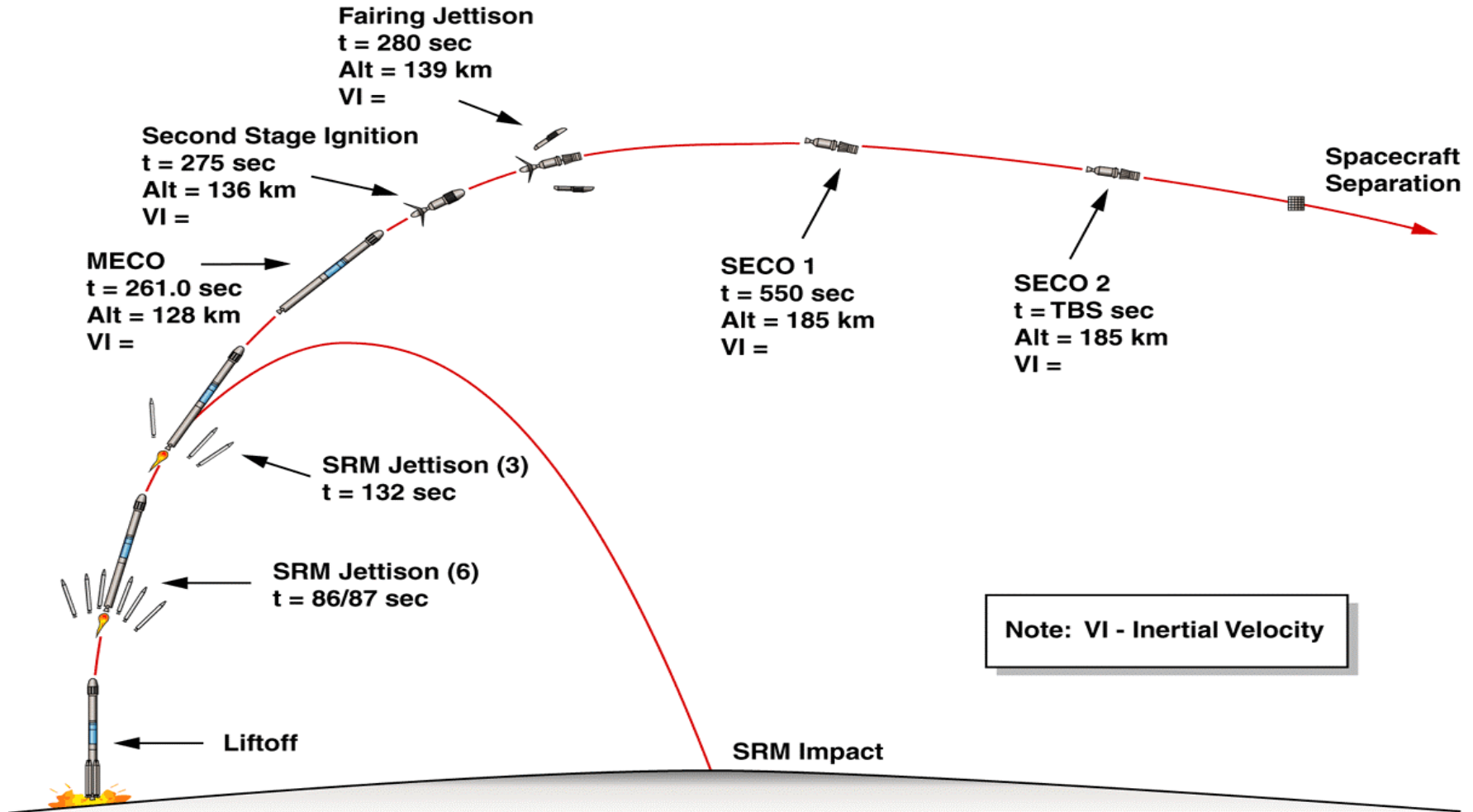
Element				Polar Power (W)	Low Inc Power (W)
Instrument Packages				80	65
Spacecraft Bus				118	118
	Power		21		
	Thermal		20		
	Attitude Control		43		
	Propulsion		2		
	C&DH		16		
	Communications		11		
	Harness		5		
Total Per Satellite				198	183
Solar Array Capability (BOL)				400	400
Power Margin (BOL)				102%	119%
Solar Array Capability (EOL)				340	340
Power Margin (EOL)				72%	86%

Values are best estimates and do not include contingency.





Typical Delta II 7920-10 Launch Profile



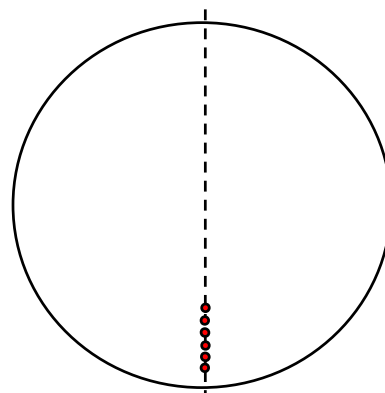
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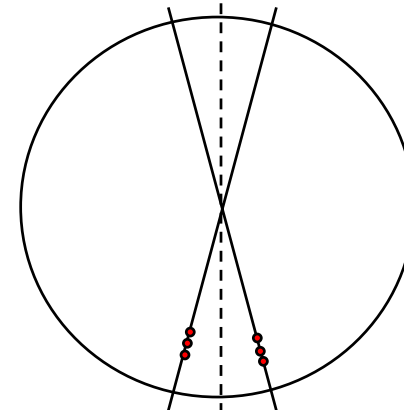
IM Orbital Pictorial

Deployment Sequence

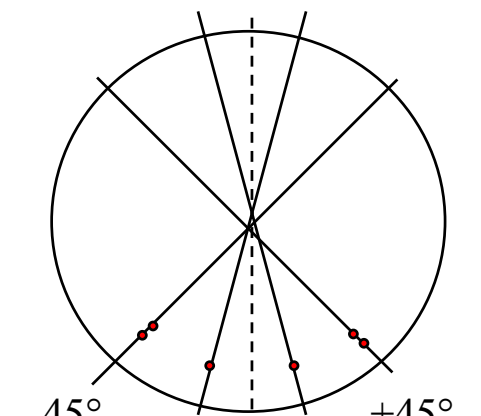
- Launch vehicle delivers three spacecraft each to two near polar orbits at inclinations of 85 and 89 degrees, respectively.
- Using the difference in nodal regression rates for each inclination, allow the two orbit planes to separate.
- At selected separations, maneuver spacecraft to inclination of 87 degrees.
- Repeat until desired configuration of 6 orbit planes, 30 degrees apart, is attained.



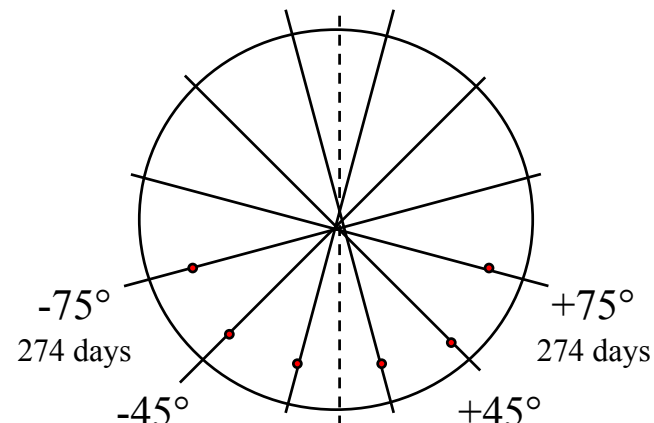
"Launch Plane"
(Zero reference)



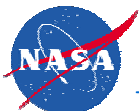
-15° 55 days +15° 55 days



-45° 164 days -15° 55 days +15° 55 days +45° 164 days



-75° 274 days -45° 164 days -15° 55 days +15° 55 days +45° 164 days +75° 274 days

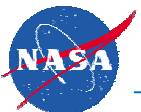




IM Orbit Parameters

The parameters for the final mission orbits are given below:

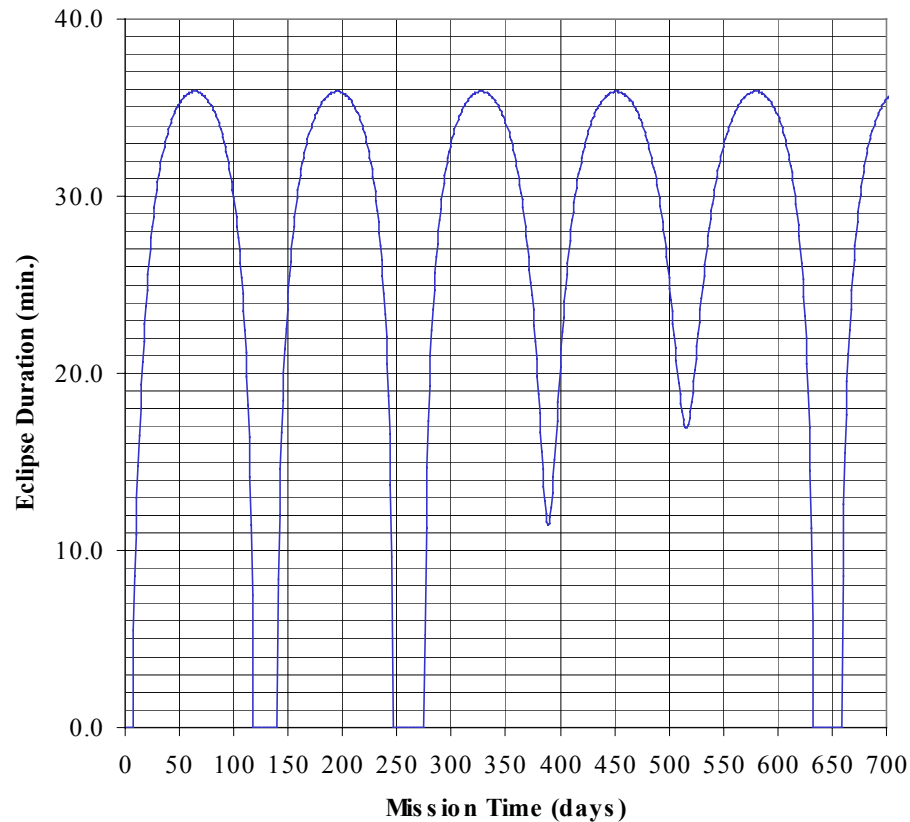
- Altitude: 450 km circular
- Period: 93.6 minutes
- Inclination:
 - Six polar orbiting satellites at 87°
 - Two low inclination satellites between 15° and 45°
- Simultaneous polar coverage, multiple mid-latitude coverage





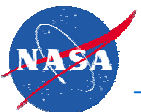
IM Shadow Periods

Eclipse Duration For IonMapper Mission With: 87° Inclination; 450 km x 450 km Altitude;
0° Initial Ascending Node Position; 0° Initial Perigee Position; 2 Year Mission Life;
01/01/2009 Launch Date



The maximum shadow period for the specified orbit is 36 minutes.

There are also brief periods of full sun orbits over the life of the mission.



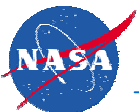
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IM Spacecraft Features

IM spacecraft features include:

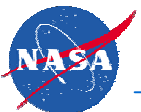
- An identical, mission-unique, three-axis stabilized bus design for each satellite
- Commonality with the RBM bus structure and subsystems, wherever possible, to achieve economies of scale for both missions
- Incorporation of new technologies that have a high probability of being available by the start of implementation
- Deployable instrument booms and wire antennas
- Body-mounted solar arrays to accommodate instrument field-of-view requirements
- A payload processor for all the instrument packages as an integral part of the C&DH subsystem





IM Mechanical Subsystem

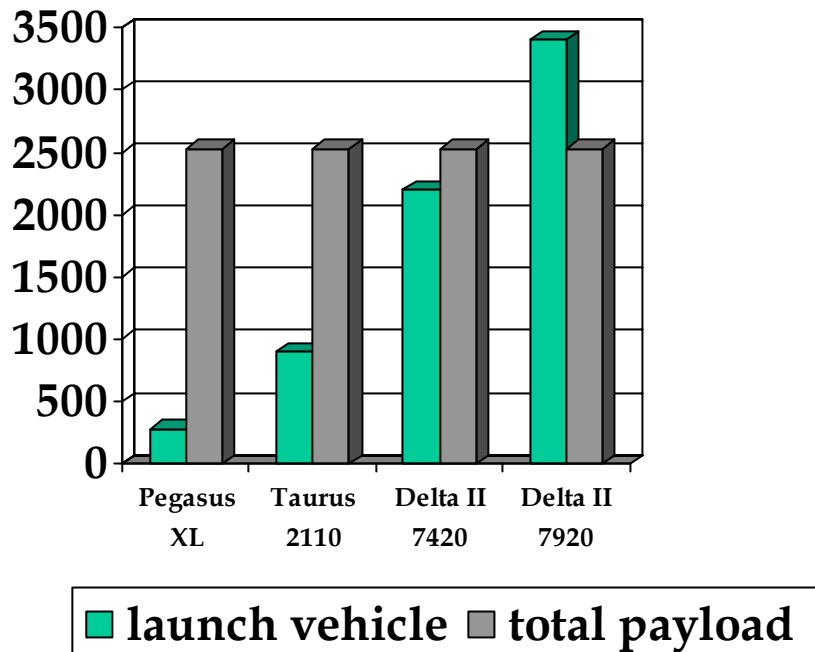
- The IM Mechanical Subsystem relies on standard aerospace materials and fabrication techniques for both spacecraft and instrument support structures. Aluminum and/or composites are used to accommodate mass, thermal, or electrical constraints.
- Spacecraft are stacked for launch and mounted to the launch vehicle payload adapter fitting by means of a mission-unique transition adapter.
- Deployment of the following items is critical for mission success:
 - Magnetometer boom
 - Langmuir probe
 - E-field booms





IM Launch Vehicle Evaluation

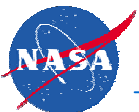
Launch vehicle payload capability (kg)
versus total IM payload (6 satellites)



In an effort to minimize launch costs, several classes of launch vehicles that could deliver the IM payload to a 450 km circular orbit from WTR were evaluated.

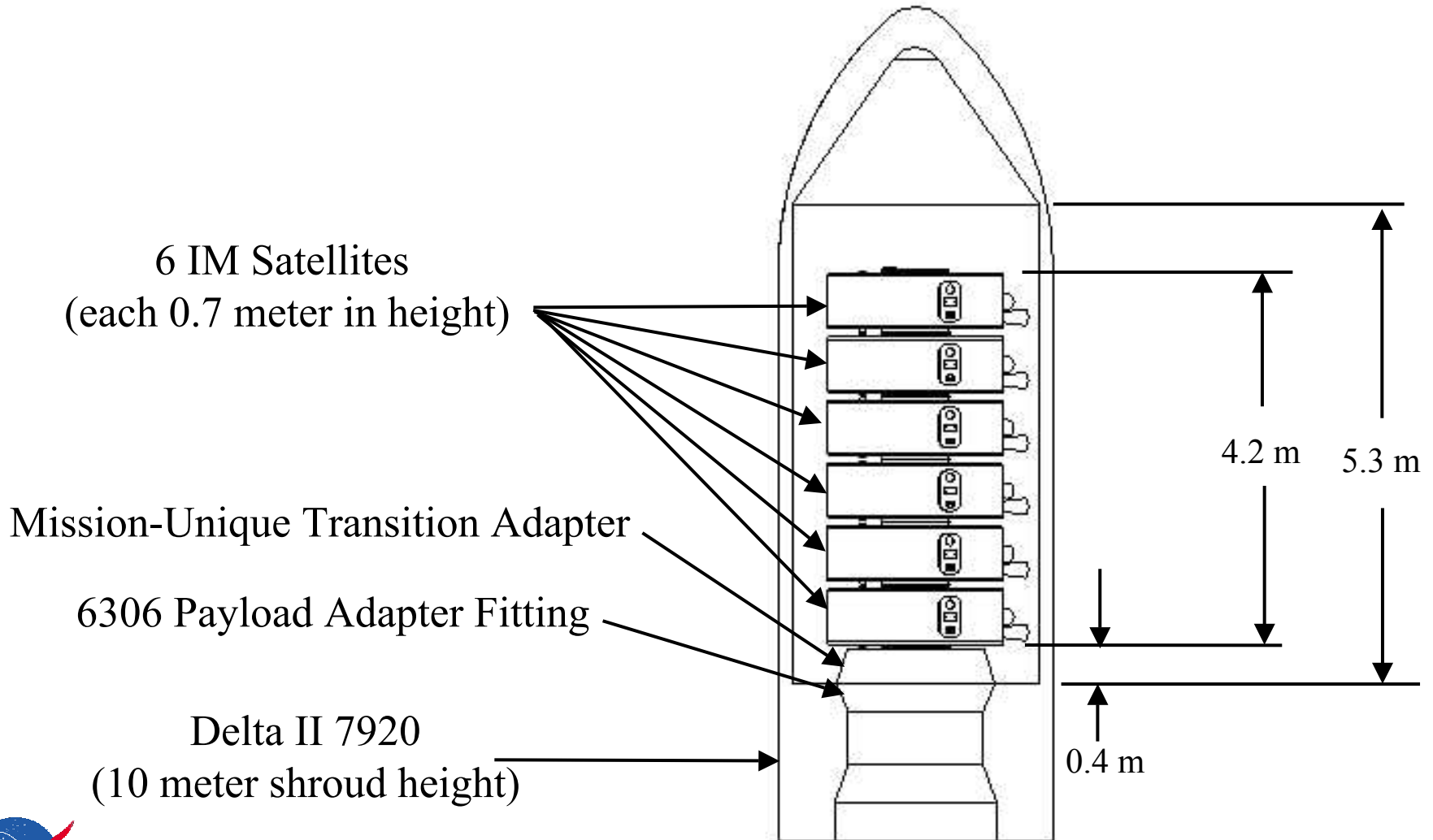
The chart on the left illustrates that the Pegasus XL, Taurus 2110 and Delta II 7420 do not have adequate lift capability. Although multiple Pegasus or Taurus launch vehicles could meet the requirement for placing 6 satellites in orbit, the cost would exceed that of a single Delta II 7920.

The Delta II 7920-10 was thus chosen for the concept study.





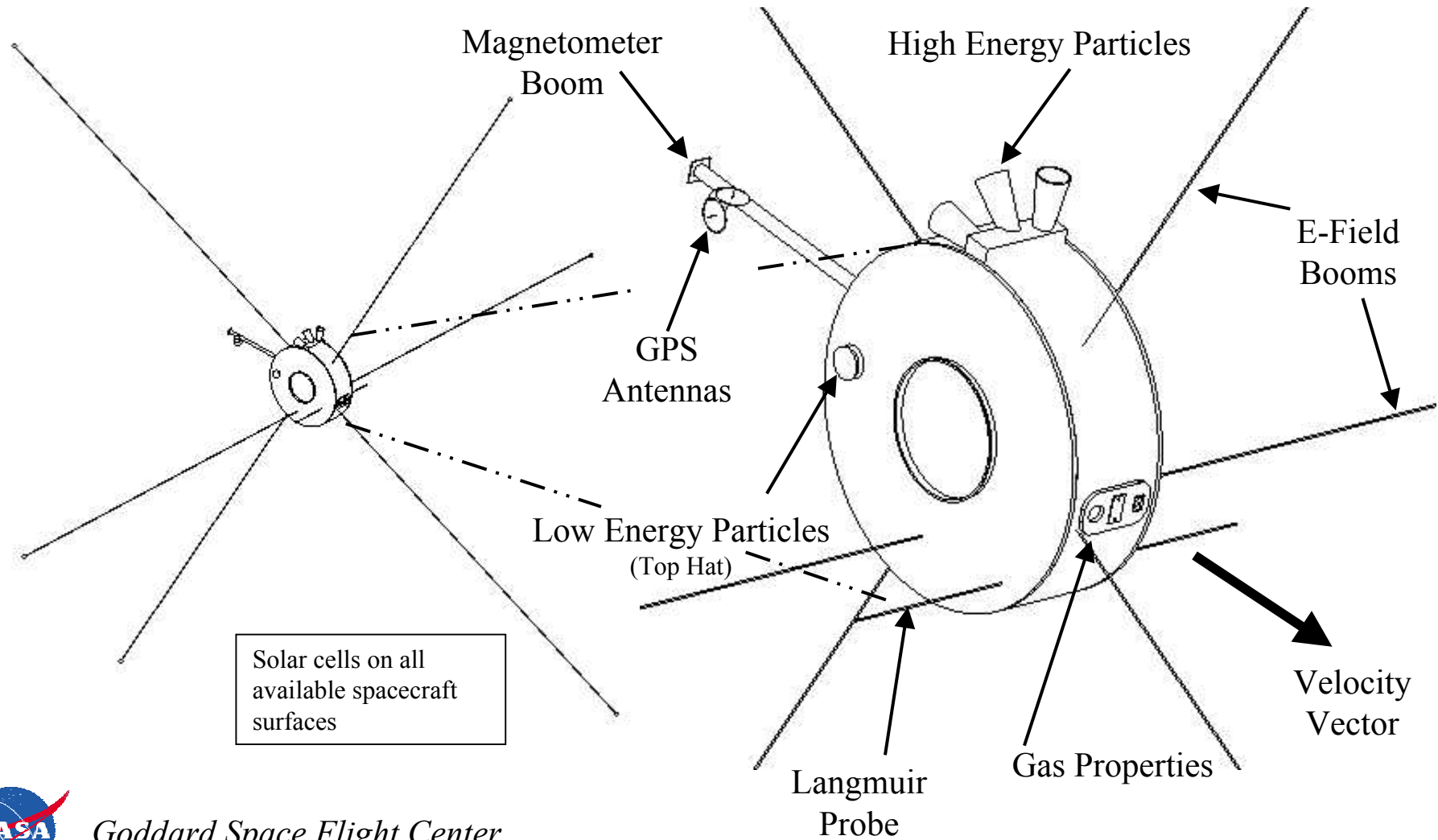
IM Polar Launch Configuration



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IM Orbit Configuration



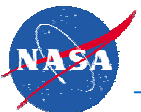


IM Power Subsystem

The Power Subsystem is a 28-volt direct energy transfer system that can support a load of 400 watts at BOL. It consists of the following elements:

- A triple junction GaAs body-mounted solar array with a projected cell area of 1.54 m²
- A single 13.1 ampere hour NiH₂ battery sized to handle transfer orbit conditions, the worst-case shadow period, and peak power demands
- Power supply electronics

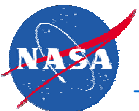
Solar array degradation over the life of the mission due to UV exposure, ionizing radiation, thermal cycling, and system losses has been taken into account in the array sizing.





IM Thermal Subsystem

- A passive thermal design approach has been adopted for control of instrument and spacecraft components.
- Radial and circumferential heat pipes are used to couple instrument and spacecraft heat sources to solar array surfaces that also serve as radiators.
- Blankets, heaters, and thermal coatings provide local control as needed.
- Instrument electronics are maintained between 0° and 20° C.
- Spacecraft components are maintained between 0° and 40° C.
- Propulsion system components are maintained above 12° C but below 40° C.

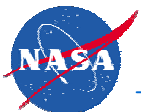




IM Attitude Control Subsystem

The Attitude Control Subsystem (ACS) proposed for the IM satellites can accommodate the instrument pointing accuracy and knowledge requirements as specified below:

- Pointing Accuracy: 3° (1 sigma) about ram direction as driven by the gas properties package
- Attitude Knowledge: 0.1° (1 sigma)



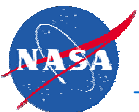


IM Attitude Control Subsystem (continued)

The ACS integrates the following complement of hardware to achieve the required pointing accuracy and knowledge for the IM mission:

- Attitude Control Electronics
- Coarse Sun Sensor
- Digital Sun Sensor
- Gyro
- Reaction Wheels
- Earth Sensor Assembly
- Magnetic Coil

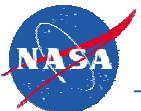
Data from the magnetometer and GPS transceiver that are part of the instrument packages are also used to support ACS functions.





IM Propulsion Subsystem

- The IM Propulsion Subsystem employs a mono-propellant, liquid hydrazine, blow-down system similar to that used for the MAP spacecraft.
- The total ΔV requirement for each satellite is about 450 m/s and includes allotments for a 2° plane change (267 m/s), orbit altitude maintenance (82 to 130 m/s), and disposal.
- The hydrazine propellant mass for each satellite was estimated to be about 79.5 kg for a 2 year mission.





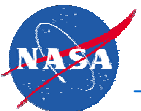
IM C&DH/ Communications Subsystem

The IM flight Command and Data Handling Subsystem is housed in a single package containing 5 cards including a payload processor function for science data ingest and a solid state 10 Gbyte memory. This storage capacity allows about 48 hours of data to be recorded and thus provides the capability to miss a scheduled downlink. A longer than normal contact time or two contacts on the following day could then be used to prevent any loss of data.

The Communications Subsystem consists of the following:

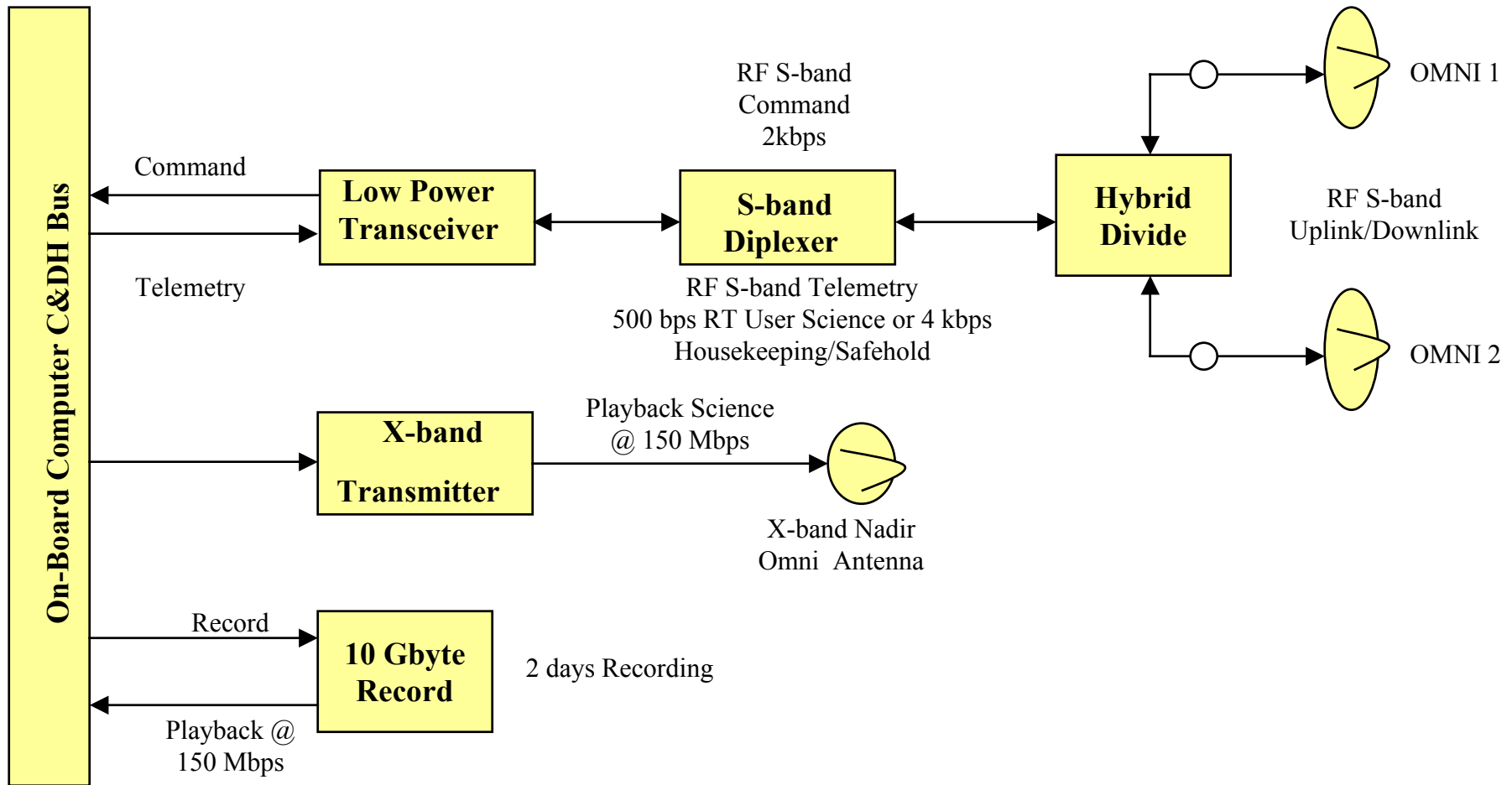
- an X-band system for downlink of science data utilizing a single X-band omni antenna on the nadir pointing axis (one contact per day per satellite) and
- an S-band system with 2 omni antennas for real time user science and for housekeeping and contingency.

All satellites operate at the same frequency but must avoid the DSN frequency allocation of 2290 MHz.





IM C&DH / Communications Subsystem





IM Ground System

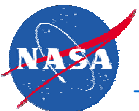
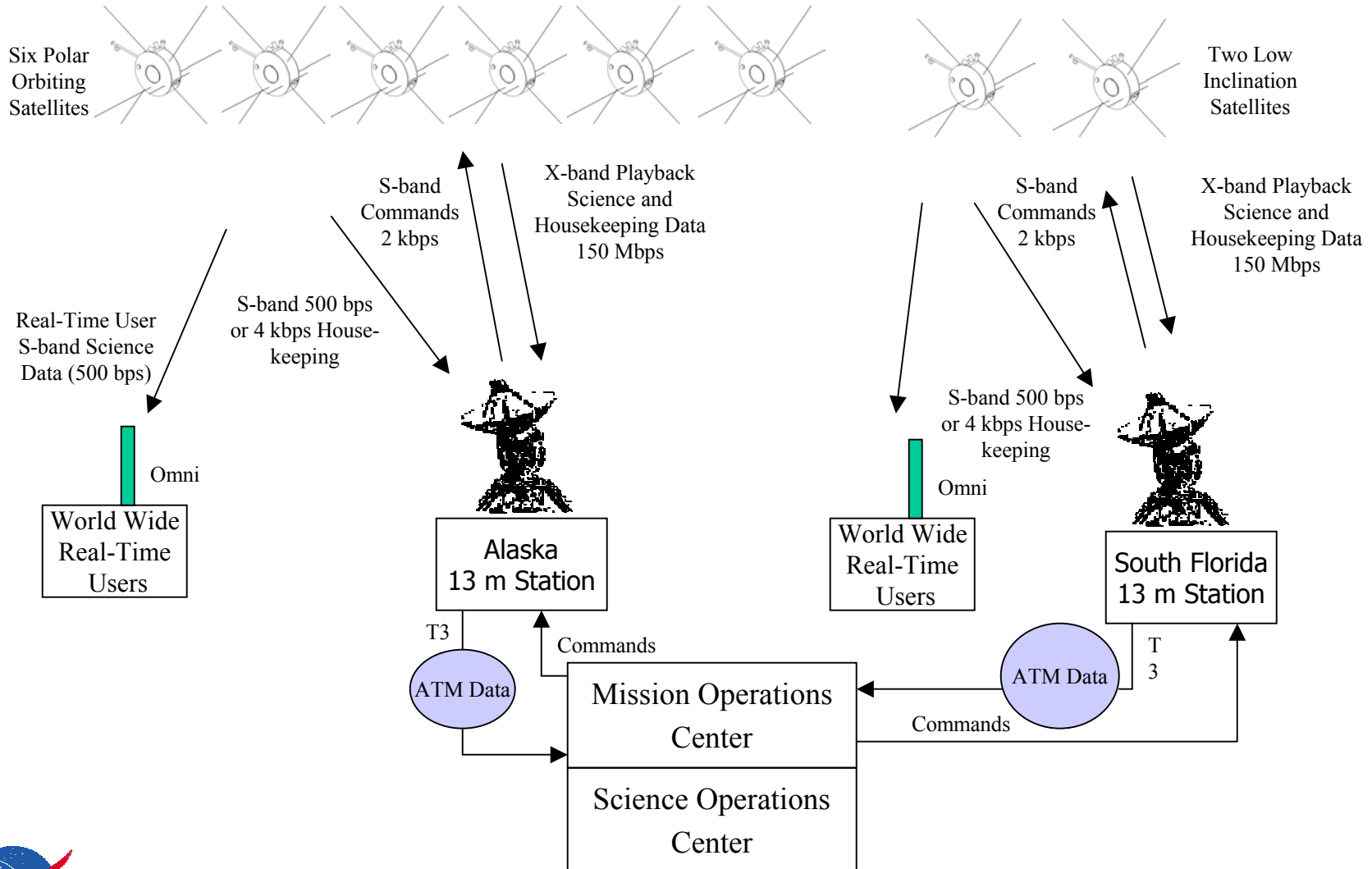
The proposed Ground System architecture for the constellation of IM satellites takes advantage of existing assets and infrastructure. System elements include the following:

- Existing 13 meter stations in Alaska for the polar satellites and in Florida for the low inclination satellites
- On-board GPS used for orbit determination (no ranging required)
- Mission Operations Center at GSFC or other feasible location
- Real-time, continuously broadcast data stream (500 bps) with potential users responsible for receiving and decoding





IM Ground System Concept



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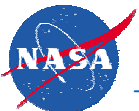
IM Mission Operations



A Mission Operations concept has been chosen that encourages automation of routine spacecraft functions and makes use of commercial off-the-shelf (COTS) products.

Salient features include the following:

- Combined Mission and Science Operations Center (MSOC) co-located with dedicated ground station at GSFC or other suitable location
- Automated mission operations using COTS command and control system
- Science data processed to Level Zero and short-term archival at MSOC
- Data distribution to Principal Investigators (PIs) via ftp sites
- On-board recording of health and safety data to support anomaly resolution

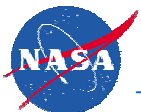




IM Science Data Distribution

The IM Science Data Distribution provisions include the following:

- Recovery of 95% of all science data
- Generation of Level 1 science data products and delivery to an existing DAAC within 48 hours of in-orbit measurement
- Traditional archive, retrieval, order, and browse functions via the DAAC





IM Mission Specific Technology

The IM mission concept incorporates new technology that is expected to be available in the near term. Such items include:

- High-efficiency, triple-junction, GaAs solar cells
- Li-ion battery (future consideration)
- Low power, lightweight, GPS transceiver
- Miniature Earth horizon sensor

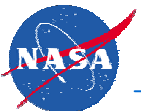




IM Study Options

Although the orbital parameters chosen by the science team for the IM mission are readily achievable, the best way to deliver six satellites into the desired polar orbit planes required study. Delivery methods evaluated included direct insertion, use of on-board propulsion, and nodal regression.

It was concluded that taking advantage of nodal regression from two interim polar orbits would achieve the desired orbital configuration with a minimum ΔV requirement. Even though this method requires about nine months before the satellites are all in their final positions, valuable science data can be taken during the transition period.

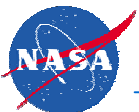


IM Preliminary Risk Assessment



During the course of the IM concept study, a number of risk areas were identified and are listed below. Further study will be required to fully assess these risks, their potential impact, and mitigation strategies.

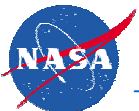
- Based upon initial mass estimates, the c.g. of six stacked satellites is higher than allowed by the Delta II 7920 launch vehicle.
- Fairing access to allow on-stand off-loading of propellant from six stacked satellites in the event of an emergency will require special provisions.
- Use of heat pipes in the thermal control system has implications for integration and testing.
- A low power transceiver has not yet been flight qualified.
- Although conservative assumptions have been made, availability of other anticipated technology enhancements must be assessed at regular intervals.





IM Study Recommendations

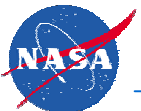
- Conduct a survey of instruments now under development or planned for future development to ensure adequacy of assumed IM instrument resource requirements
- Assess the feasibility of combined packaging of multiple instruments
- Evaluate the use of elliptical orbits to achieve science objectives
- Identify methods of reducing the c.g. of the stacked satellite configuration
- Pursue commonality of IM/RBM instrument and spacecraft designs
- Consider unique manufacturing techniques such as investment casting to reduce spacecraft structure costs
- Develop a more detailed mission operations concept for the full complement of satellites
- Determine if a frequency authorization for continuous radiation (real-time data broadcast) can be obtained
- Compare the new technology flywheel storage approach with the traditional battery system
- Identify technology and/or process developments needed to build and test multiple research grade flight instruments and spacecraft





Acronyms

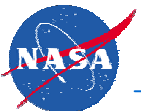
ACE	Attitude Control Electronics
ACS	Attitude Control Subsystem
ATM	Asynchronous Transfer Mode
BOL	Beginning Of Life
C&DH	Command and Data Handling
COTS	Commercial Off-The-Shelf
DAAC	Distributed Active Archive Center
DE	Dynamics Explorer
DSN	Deep Space Network
ELV	Expendable Launch Vehicle
EOL	End Of Life
ETR	Eastern Test Range
FOO	Flight Of Opportunity
GaAs	Gallium Arsenide
GEC	Global Electrodynamics Connections





Acronyms (continued)

GPS	Global Positioning System
GSFC	Goddard Space Flight Center
HQ	Headquarters
IM	Ionospheric Mappers
IMDC	GSFC Integrated Mission Design Center
Li	Lithium
LWS	Living With a Star
MAP	Microwave Anisotropy Probe
MECO	Main Engine Cut-Off
MMS	Magnetospheric Multiscale
MSOC	Mission and Science Operations Center
NASA	National Aeronautics and Space Administration
PI	Principal Investigator
RBM	Radiation Belt Mappers





Acronyms (continued)

RF	Radio Frequency
RT	Real Time
SECO	Secondary Engine Cut-Off
SRM	Solid Rocket Motor
SS	Sun Sensor
TBS	To Be Supplied
UV	Ultraviolet
WTR	Western Test Range

